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Indian Standard

METHODS FOR MEASUREMENT OF FREQUENCY AND EQUIVALENT RESISTANCE OF UNWANTED RESONANCES OF FILTER CRYSTAL UNITS

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METHODS FOR MEASUREMENT OF FREQUENCY AND EQUIVALENT RESISTANCE OF UNWANTED RESONANCES OF FILTER CRYSTAL UNITS

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Sectional Committee, ETDC 51

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Indian Standard

METHODS FOR MEASUREMENT OF FREQUENCY AND EQUIVALENT RESISTANCE OF UNWANTED RESONANCES OF FILTER CRYSTAL UNITS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 16 February 1976, after the draft finalized by the Piezoelectric Devices for Frequency Control and Selection Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 The object of this standard is to provide the methods for measurement of frequency and equivalent resistance of unwanted resonances of filter crystal units.

0.3 In preparing this standard assistance has been derived from the IEC Publication 283-1968 'Methods for the measurement of frequency and equivalent resistance of unwanted resonances of filter crystal units' issued by the International Electrotechnical Commission.

0.4 In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

1. SCOPE

1.1 This standard describes the methods for measurement of frequency and equivalent resistance of unwanted resonances of filter crystal units.

2. GENERAL

2.1 Two methods for measurement of frequency and intensity of unwanted responses of filter crystal units have been described in this standard. Both methods are based on the use of a measuring bridge in which balancing of the parallel capacitance is performed at a frequency removed from the main or any unwanted resonance.

2.1.1 The first method is termed as basic method for measurement of unwanted resonances in filter crystal units (*see* Section 1).

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*Rules for rounding off numerical values (*revised*).

2.1.2 The second method is termed as reference method for measurement of frequency and equivalent resistance of unwanted responses of filter crystal units (*see* Section 2).

2.2 The intensity of the unwanted response is indicated by the maximum output voltage occurring during transmission of the unwanted resonance frequency.

2.3 According to the first method, the load capacitance and termination are specified. The intensity of the main and unwanted resonance is indicated by the corresponding level difference of the bridge output voltage with respect to its level when short-circuiting the crystal unit under test. According to the second method, which is a development of the first one, the load resistance of the bridge is chosen to be small and specified for each frequency range.

2.4 To determine the intensity of an unwanted response in addition to the initial balance of the bridge removed from resonances, an additional balancing is carried out at two frequencies which are symmetrical with respect to the unwanted response measured. The equivalent resistance of the unwanted response is calculated from the difference between the level of the two frequencies mentioned above and the level at the unwanted resonance frequency.

2.5 The second method requires more time for measurement than the first one, but it can give more accurate measurement.

SECTION I BASIC METHOD FOR MEASUREMENT OF UNWANTED RESONANCES IN FILTER CRYSTAL UNITS

3. SCOPE

3.1 This section describes basic method of detecting unwanted resonances in crystal units and methods of measuring the magnitude of response or response deviation at these frequencies.

4. PRINCIPLE OF MEASUREMENT

4.1 The scheme of measurement used is to supply a continuously adjustable frequency to a standard bridge and to observe the transmission response over the frequency range specified for the individual crystal unit.

4.2 The standard bridge consists of a hybrid coil forming two arms of the bridge, the individual crystal unit under test and the balancing capacitor in the other two arms. This bridge represents a properly terminated, narrow band crystal filter with the widest possible pass band. The frequency of maximum transmission is not identical with the resonance frequency of the crystal unit.

4.3 The bridge unbalance output is continuously indicated over the frequency range specified for the individual crystal unit to permit detection of irregularities from a normally smooth transmission characteristic, the irregularities being due to unwanted resonances of the crystal unit under test.

4.4 The magnitude of the transmission response deviation is given by either of the following:

a) *The Differential Response* — Difference in level expressed in decibels between the turning points of the characteristic in the vicinity of the unwanted response (*see* Fig. 1).

b) *The Absolute Response* — Transmission difference expressed in decibels at the unwanted resonance frequency with and without the crystal unit short-circuited (*see* Fig. 1).

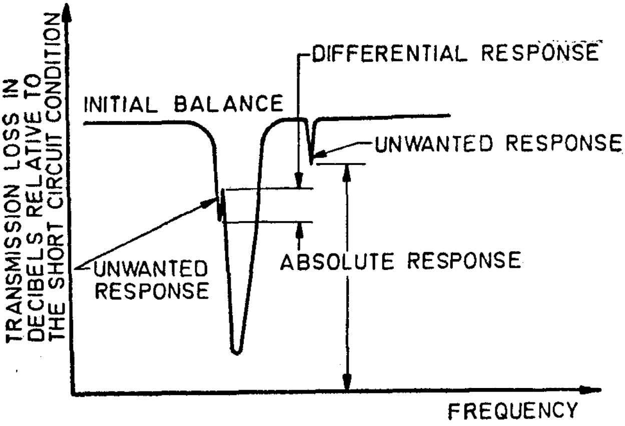
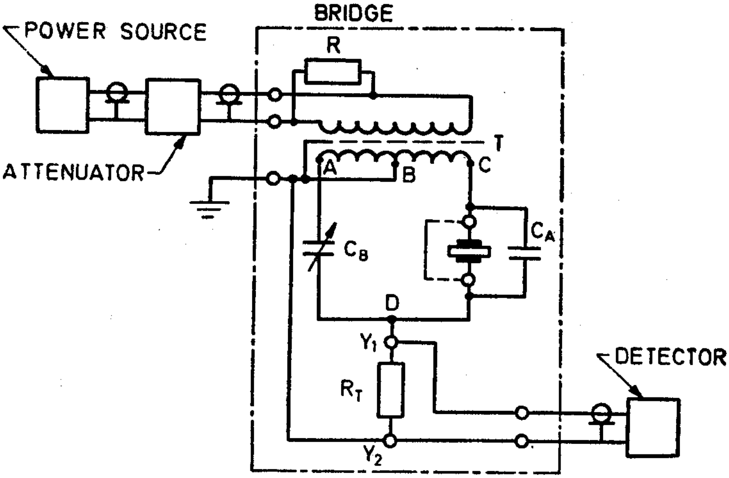


Fig. 1 Illustration of Differential and Absolute Response

5. MEASURING CIRCUIT

5.0 Unwanted resonances are detected and measured by means of a circuit consisting of a power source, an attenuator, a bridge, terminating resistors and a detector or their electrical equivalents connected as shown in Fig. 2.

5.1 Requirements for the Power Source — Within ±10 percent of the nominal series resonance frequency of the crystal unit under test, side bands should be down by at least 80 dB. Harmonics of the output frequency and the selectivity of the detector should be such that the level of harmonics is at least 60 dB below the fundamental at the detection element. Harmonic suppression filters may be used, if necessary.



R_T = terminating resistor (*see* **5.4**).
C_A = fixed capacitor 3·5 pF. Used only when C_0 of crystal unit is less than 3·5 pF.
C_B = low-loss adjustable air capacitor 3·5 to 50 pF (with ceramic insulators) adjustability:
0·002 pF at minimum capacitance
0·015 pF at maximum capacitance
R = matching resistor of attenuator
T = transformer. For a primary impedance matched to the attenuator, the secondary impedance shall be smaller than $\frac{R_T}{5}$
R-75 Ω + 5 percent = suggested values (for example)
75 Ω = primary impedance
110 Ω = secondary impedance
$>$30 dB = secondary balance
$\ngtr$0·5 dB = transformer loss variation over the frequency range to be used.

FIG. 2 CIRCUIT DIAGRAM

5.2 Requirements for the Detector — The sensitivity shall be such that in conjunction with the power source used, bridge output levels 85 dB below the output level with the crystal unit short-circuited may be detected. The differential sensitivity shall permit observation of 0·1 dB changes in input level.

The requirements for input capacitance and resistance are given in **5.3** and **5.4** respectively.

5.3 Requirements for the Bridge Circuit

5.3.1 *Requirements for Balance* — When using a high quality air capacitor in place of the crystal unit, the bridge shall be capable of balance to the degree specified in **6.1.2** over the scanned frequency range without further adjustment.

5.3.2 *Requirements for Direct Capacitances* — The direct capacitance between two conductors is the capacitance value equal to the charge produced on one of the conductors by the voltage between the two conductors divided by that voltage. It can be measured on a capacitance measuring bridge where both conductors are connected to the measuring terminals of the bridge; all other conductors are connected to the centre location (neutral point) of the bridge, so as to exclude them from the measurement. The limiting values of the direct capacitances shall be as specified below:

Direct Capacitance Between Points (see *Fig.* 2)	*Condition*	*Requirement* pF
D and C	C_A disconnected	1 *Max*
D and A	C_B at minimum	3·7 *Max*
D and B	Terminals Y_1 and Y_2 open detector connected and powered	8 ± 1

NOTE — The grounded capacitance of a conductor is the capacitance of this conductor to earth when all other conductors are connected to earth.

Measurement of the direct capacitances will be facilitated by disconnecting the transformer T at points A and C.

The direct capacitance C_{DB}, between points D and B, shall be determined by measuring the grounded capacitance C_D of point D, the direct capacitances C_{DA} between points D and A, and C_{DC} between points D and C, and taking the differences as follows:

$$C_{DB} = C_D - C_{DA} - C_{DC}$$

5.4 Requirements for the Terminating Resistor — The value of the terminating resistor R_T is based on the proper termination of the electrical lattice equivalent of the specified bridge circuit. The input resistance of the detector may be part of R_T.

It is determined as follows:

$$R_T = \frac{16 \times 10^7}{f_s (2 C_B + C_R)} \ \Omega \text{ or } 220\,000 \ \Omega$$

whichever is smaller

where

f_s = nominal series resonance frequency in kHz of the crystal unit under test;

$C_B = C_0 + C_A$ where C_0 is the parallel capacitance in pF of the crystal unit under test and C_A is an additional capacitance; and

C_R = the direct capacitance in pF between points *B* and *D* (*see* Fig. 2); it has a value between 7 pF and 9 pF (*see* **5.3.2**).

The terminating resistor should have a tolerance of ±5 percent and preferably be chosen with a standard value. The shunt capacitance of the terminating resistor should not exceed 1 pF.

6. METHOD OF MEASUREMENT

6.0 The output of the power source is adjusted in such a manner that the maximum level of drive for the crystal unit under test is not exceeded for the specified condition of operation. Measurement of unwanted resonances is made by first balancing out the static capacitance of the crystal unit and then observing the bridge output over the frequency range to be scanned.

NOTE — Measurement shall be carried out under static conditions; frequency scanning shall be allowed provided that adequate correlation with the static method has been established.

6.1 Initial Balance

6.1.1 The initial balance frequency should be sufficiently removed from the nominal series resonance frequency in order that the balance will primarily represent balancing of the parallel capacitance C_0 of the crystal unit.

The balance frequency normally shall be such that the scanned frequencies lie within an octave each side of the balance frequency.

6.1.2 The initial balance value is the difference expressed in decibels measured at the balance frequency between the levels with and without the crystal unit short-circuited.

The initial balance shall be one of the following:

a) For absolute responses, at least 20 dB more than the specified limit of the crystal unit under test.

b) For differential responses, at least 20 dB more than the level of the otherwise smooth curve at the unwanted response frequency.

c) The greater of (a) and (b) above, if both absolute and differential response requirements have been specified for the crystal unit.

6.2 Absolute Response Measurement

The initial balance is performed. The frequency for maximum transmission at the unwanted resonance is adjusted. The attenuator setting for a given detector deflection is then noted.

The crystal unit is short-circuited and the attenuator is adjusted for the same detector deflection. The difference in decibels between the two attenuator settings is the absolute response.

6.3 Differential Response Measurement

The initial balance is performed. The frequency is adjusted to the peak of the unwanted response. The attenuator setting is noted for a given detector deflection. The frequency is slowly adjusted to the trough of the same unwanted response and the attenuator is readjusted to give the same detector deflection as for the peak of the unwanted response. The difference in decibels between the two attenuator settings is the differential response.

SECTION 2 REFERENCE METHOD FOR MEASUREMENT OF FREQUENCY AND EQUIVALENT RESISTANCE OF UNWANTED RESPONSES OF FILTER CRYSTAL UNITS

7. SCOPE

7.1 This section describes reference method for measurement of frequency and equivalent resistance of unwanted responses of filter crystal units.

8. PRINCIPLE OF MEASUREMENT

8.1 The crystal unit to be measured is inserted in a measuring bridge, the output of which is shunted by a low resistance. The parallel capacitance of the unit is balanced and the frequency is varied over the range to be explored. For any unwanted response encountered in this range, the frequency is determined as the frequency for which the unbalance output of the bridge shows a maximum.

The equivalent resistance can be calculated from the difference between the maximum and the minimum unbalance bridge output around that unwanted response.

9. MEASURING CIRCUIT

9.0 The measuring circuit used for this method is shown in Fig. 3. Explanation of this method is given in Appendix A.

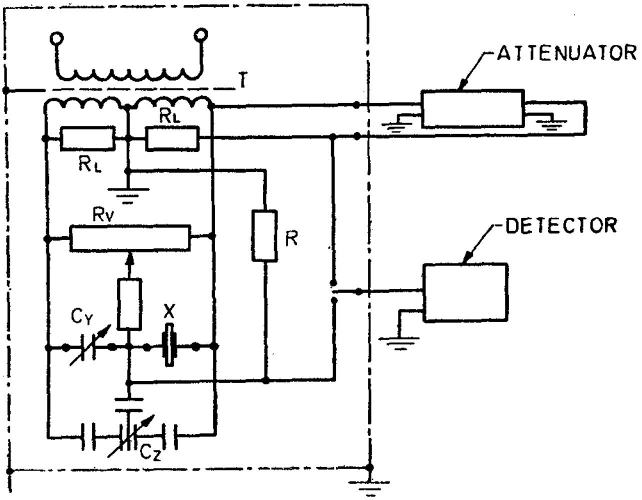


FIG. 3 MEASURING CIRCUIT OF FREQUENCY AND EQUIVALENT RESISTANCE OF UNWANTED RESONANCES OF FILTER CRYSTAL UNITS BY THE REFERENCE METHOD

9.1 Power Source — At both sides of the frequency for which the power source is adjusted, and within 10 percent of that frequency, the total output apart from that at the adjusted frequency shall be at least 80 dB below the main output. When measured at the detection element, the output at any harmonic of the frequency for which the power source is adjusted shall be at least 60 dB below the output at the fundamental frequency. Harmonic suppression filters may be used, if necessary.

9.2 Detector — The sensitivity shall be such that, in conjunction with the power source used, it would be possible to detect:

a) a change of 1 dB in input level, and

b) an output level of the bridge 45 dB below the level obtained when a resistor equal to 100 R is connected instead of the crystal unit (R = value of terminating resistor).

The absolute value of the input impedance shall not be less than 30 R. Selectivity reference shall be in accordance with **10.1**.

9.3 Bridge Circuit — The bridge circuit shall be such that it satisfies the test given in **9.3.1**.

9.3.1 A capacitor of high quality and of appropriate capacitance is connected instead of the crystal unit. The initial balance is performed in accordance with **10.1.** The specified frequency range is scanned and the unbalance output voltage is observed, which shall not change by more than 10 dB.

NOTE — Commercially available admittance bridges may also be used, provided that correlation has been achieved.

9.4 Terminating Resistor R — The resistance of the terminating resistor R shall be much smaller than the absolute value of the impedance of the balance impedance.

Practical values are:

$R =$ 3 300 ohms for frequencies below 100 kHz

$R =$ 330 ohms for frequencies between 100 kHz and 1 MHz

$R =$ 33 ohms for frequencies between 1 MHz and 10 MHz

$R =$ 10 ohms for frequencies between 10 MHz and 100 MHz

The tolerance shall be ±5 percent.

9.5 Load Resistor R_L — The load resistors R_L are matched to the characteristic impedance of power source and connecting cable.

10. METHOD OF MEASUREMENT

10.1 Initial Balance — The output of the power source is so adjusted that the maximum level of drive specified for this measurement for the crystal unit under test is not exceeded at any frequency within the test frequency range.

The frequency is adjusted at a value well away from the resonance frequency of the main resonance, and away from any unwanted mode. This frequency shall, however, be such that the frequency range to be scanned is within one octave on either side.

The detector deflection due to the residual unbalance output voltage across the terminating resistor R is noted and the attenuator is adjusted to give the same detector reading. The attenuation shall not be less than 85 dB.

10.2 Response Measurement — The specified frequency range is scanned and when an unwanted mode is detected, the bridge balance is readjusted to give an unbalance output at both sides of the maximum output which is at least 20 dB less than the maximum output at the peak of the unwanted response.

The frequency is then adjusted to the peak of the unwanted resonance and the detector reading is noted. The attenuator is adjusted to give the same detector reading.

The equivalent resistance of the unwanted mode is then:

$$R_{\mathrm{m}} = R \times 10^{x/20}$$

where x = attenuator reading in decibels

10.3 Routine Measurements — When a series of equal crystal units has to be measured, the balance capacitor C_{y} may be replaced by a reference crystal unit having a series resonance frequency and a motional inductance within close tolerances of their nominal values. This reference crystal unit shall be free from unwanted modes within the frequency range to be scanned.

The unbalance output is then a direct measure for the equivalent resistance of the unwanted response and the bridge output voltage may, therefore, be recorded as a function of frequency.

APPENDIX A

(*Clause* 9.0)

EXPLANATION OF THE REFERENCE METHOD FOR MEASUREMENT OF FREQUENCY AND EQUIVALENT RESISTANCE OF UNWANTED RESPONSE OF FILTER CRYSTAL UNITS

A-1. A crystal unit with unwanted resonances may be represented by an equivalent diagram with $n + 1$ (*see* Fig. 4), instead of one motional branch (C_1 L_1 R_1 being that of the main mode).

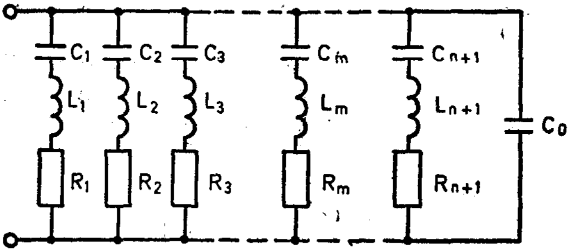


FIG. 4 EQUIVALENT CIRCUIT DIAGRAM OF A CRYSTAL UNIT WITH UNWANTED RESONANCES

By balancing out the parallel capacitance C_0 and varying the frequency applied to the measuring circuit within a certain range, the resonant frequency of each of the unwanted modes in that range can be found. The value of the equivalent resistance is derived from a measurement of the difference between the minimum and the maximum of the crystal unit impedance around that unwanted resonance.

In the circuit described in Fig. 3, balance is achieved by means of the potentiometer R_V for the real component, and by the capacitors C_Y and C_Z for the reactive component.

A-2. A simplified diagram is shown in Fig. 5 in which the variable components are represented by one admittance Y.

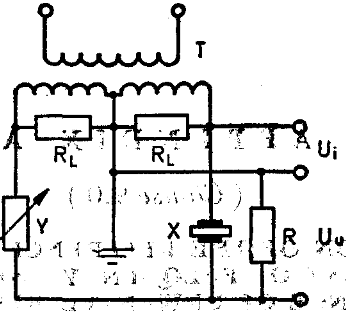


FIG. 5 SIMPLIFIED DIAGRAM

The resistors R_L are matched to the rf power source. The output of the bridge is shunted by the terminating resistor R with low resistance value. The unbalance output U_u is continuously indicated during the frequency variation.

Irregularities in the frequency characteristic are due to unwanted resonances of the crystal unit under test. The ratio of the unbalance output voltage U_u to the corresponding input voltage U_i on the bridge is measured by means of the attenuator.

For the initial balance, the admittance Y is approximately equal to ωC_0. The value of the terminating resistor R is chosen much smaller than $\frac{1}{\omega C_0}$, so that, in case of unbalance, practically all current will pass through the crystal unit and the terminating resistor. This means that, at an unwanted resonance with equivalent resistance R_m, the following equation is valid:

$$R_m = \left(\frac{U_1}{U_u} - 1 \right) R$$

or, when $R_m \gg R$ and therefore $U_1 \gg U_u$:

$$R_m = \frac{U_1}{U_u} \, . \, R$$

The bridge can be used with sufficient accuracy, only when the equivalent resistance of the unwanted mode is much bigger than the load resistance R_L.

To measure R_m accurately, the bridge shall be balanced at the point of intersection of the admittance diagram. Then the minima on both sides of the maximum admittance are equal. This also makes it possible to measure the motional resistance of an unwanted mode with sufficient accuracy, if the admittance circle of this mode is situated exactly on the admittance circle of the main resonance (*see* Fig. 6).

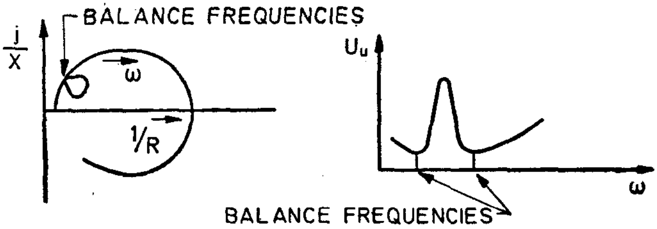


FIG. 6 ADMITTANCE CIRCLE

INDIAN STANDARDS ON PIEZOELECTRIC CRYSTALS FOR FREQUENCY CONTROL AND SELECTION

IS:

1885 (Part V)-1965 Electrotechnical vocabulary: Part V Quartz crystals

1885 (Part XXXIII)-1972 Electrotechnical vocabulary: Part XXXIII Piezoelectric filters

2916 (Part I)-1969 Quartz crystal units used in oscillators: Part I General requirements and tests

2916 (Part II)-1972 Quartz crystal units used in oscillators: Part II Type AA-01

2916 (Part III)-1972 Quartz crystal units used in oscillators: Part III Type AA-02

2916 (Part IV)-1972 Quartz crystal units used in oscillators: Part IV Type AA-03

2916 (Part V)-1972 Quartz crystal units used in oscillators: Part V Type AA-04

2916 (Part VI)-1972 Quartz crystal units used in oscillators: Part VI Type AA-05

2916 (Part VII)-1975 Quartz crystal units used in oscillators: Part VII Type AA-06

2935-1964 Guide for use of quartz oscillator crystals

4570-1968 Crystal holders

5575 (Part I)-1970 Temperature control devices for quartz crystal units (heating type): Part I General requirements and tests

6133 (Part I)-1971 Piezoelectric filter for use in telecommunication and measuring equipment: Part I General requirements and tests

6537-1972 Guide to the use of temperature control devices for crystal units

7410 (Part I)-1974 Guide to the use of piezoelectric filters: Part I Quartz crystal filters

7410 (Part II)-1975 Guide to the use of piezoelectric filters: Part II Piezoelectric ceramic filters

7957-1976 Basic method for the measurement of resonance frequency and equivalent series resistance of quartz crystal units by zero phase technique in a π-network

7962-1975 Methods of measurement for piezoelectric vibrators operating over the frequency range up to 30 MHz

8011-1976 Methods for the measurement of frequency and equivalent resistance of unwanted resonances of filter crystal units